# DVCS and extraction of cross sections in Hall A

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# Outline

- 1- Generalized Parton Distributions / DVCS
- 2- Apparatus for Hall A DVCS experiment at Jefferson Laboratory
- 3- Cross sections extraction method
- 4- Results
- 5- Conclusions

# 1- Generalized Parton Distributions / DVCS

- Ultimate goals of ep scattering:
  - Access to the quarks and gluons content of the nucleon
  - Understand QCD
- Form Factors => Charge distribution (Elastic scattering)
- Parton Distribution Functions => Quark momentum distribution (Deep Inelastic Scattering)
- GPDs => correlates both (Exclusive processes)

# 1- Generalized Parton Distributions

4 GPDs, depending on 3 variables : $H, \tilde{H}, E, \tilde{E}(x, \xi, t)$

$$H(x,0,0)=q(x)$$
$$\tilde{H}(x,0,0)=\Delta q(x)$$

Ji sum rules:

$$\int_{-1}^{1} dx H^q(x, \xi, t)=F_1^q(t)$$
$$\int_{-1}^{1} dx E^q(x, \xi, t)=F_2^q(t)$$
$$\int_{-1}^{1} dx\, \tilde{H}^q(x, \xi, t)=g_A^q(t)$$
$$\int_{-1}^{1} dx\, \tilde{E}^q(x, \xi, t)=h_A^q(t)$$

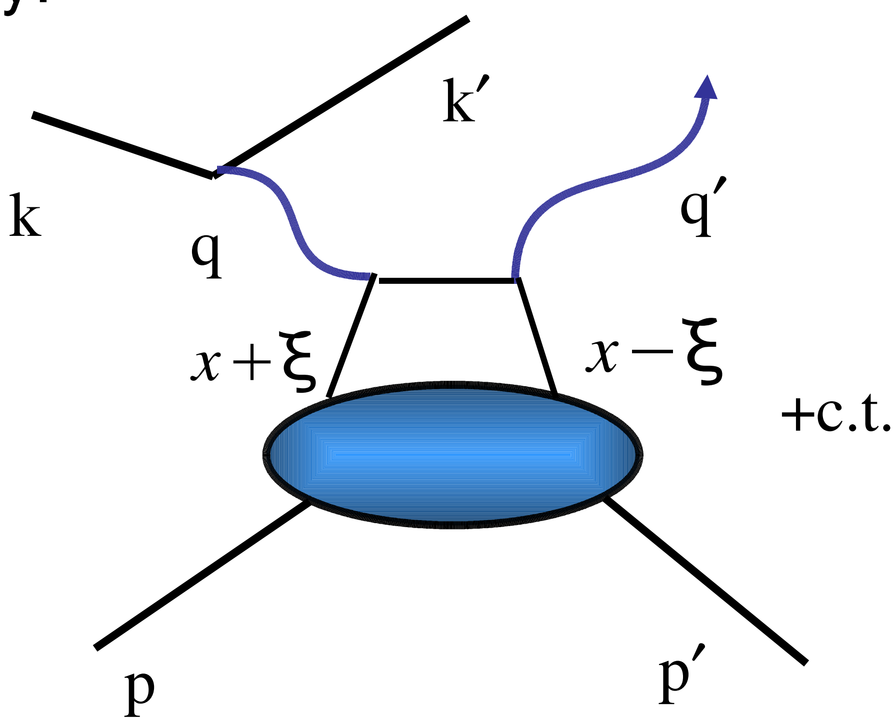
# 1- Deeply Virtual Compton Scattering

- DVCS: « cleanest way to access GPD's »
- Relevant variables of study:

$$Q^2 = (k - k')^2$$

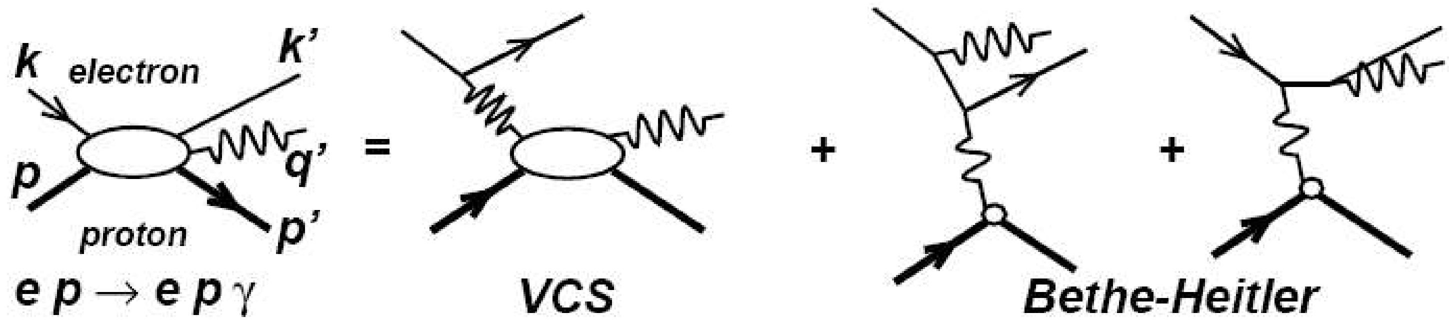
$$x_{Bj} = \frac{Q^2}{2\,p \cdot q}$$

$$t = (k - k' - q')^2$$



# 1- DVCS Cross section

$$T = T^{BH} + T^{DVCS}$$




- Cross section of the process is (*Belitsky Kirchner Müller* ***hep-ph/0112108***) :

$$\frac{d^4\sigma}{dQ^2 dx_{Bj} dt d\varphi_{\gamma\gamma}} \propto \left\{ \frac{|T^{BH}|^2 + |T^{DVCS}|^2 + I}{e^6} \right\}$$

# 1- DVCS cross section : BKM model

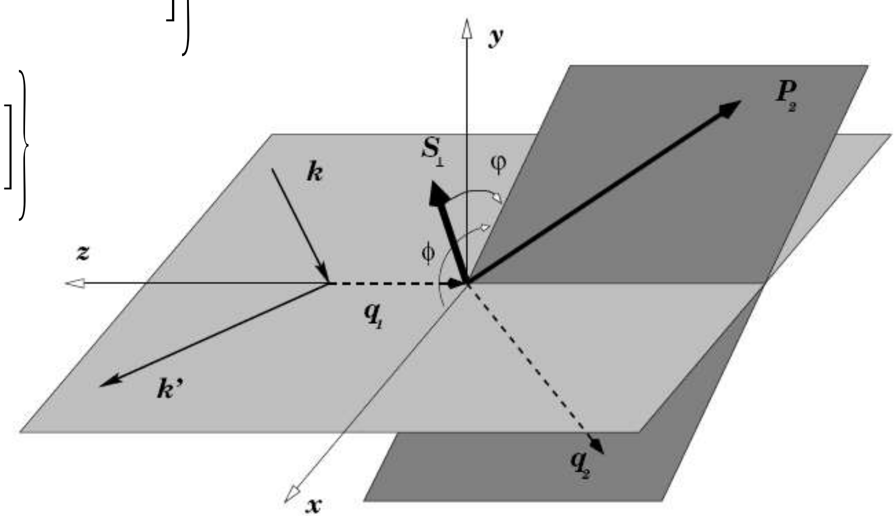
- BKM: Harmonic decomposition of cross section ($\phi_{\gamma\gamma}$ dependence)
- GPD’s encapsulated in harmonic coefficients

  => extraction of GPD’s by knowing DVCS cross section as a function of $\phi_{\gamma\gamma}$ )

$$|T^{BH}|^2 \propto \frac{1}{P_1(\varphi)P_2(\varphi)}\left\{c_0^{BH}+\sum_{n=1}^{2} c_n^{BH}\cos(n\varphi)+s_1^{BH}\sin(\varphi)\right\}$$

$$|T^{DVCS}|^2 \propto \left\{c_0^{DVCS}+\sum_{n=1}^{2}\left[c_n^{DVCS}\cos(n\varphi)+s_n^{DVCS}\sin(n\varphi)\right]\right\}$$

$$I \propto \frac{1}{P_1(\varphi)P_2(\varphi)}\left\{c_0^{I}+\sum_{n=1}^{3}\left[c_n^{I}\cos(n\varphi)+s_n^{I}\sin(n\varphi)\right]\right\}$$



# GPD dependent terms in DVCS cross section: $\phi_{\gamma\gamma}$ dependence

Bilinear DVCS amplitude harmonics:

« DVCS terms »

linear DVCS amplitude harmonics:

« interference terms »

| | Unknown | Type | $\phi$ dependance |
|---|---|---|---|
| $BH^2$ | normalisation constant | Elastic Form Factors$^2$ | $P_1^{-1}P_2^{-1}(c_0 + c_1 \cdot \cos(\phi) + c_2 \cdot \cos 2\phi)$ |
| $DVCS^2$ | $C^{DVCS}_{unp}(\mathcal{F},\mathcal{F}^*)$ | twist-2 | $c^{t}$ |
| | $\Re[C^{DVCS}_{unp}(\mathcal{F}^{eff},\mathcal{F}^*)]$ | twist-3 | $\cos\phi$ |
| | $\Im[C^{DVCS}_{unp}(\mathcal{F}^{eff},\mathcal{F}^*)]$ | twist-3 | $\sin\phi$ |
| | $\Re[C^{DVCS}_{unp}(\mathcal{F}_T,\mathcal{F}^*)]$ | twist-3 | $\cos 2\phi$ |
| $BH \cdot DVCS$ | $\Re[C^{I}_{unp}(\mathcal{F})]$ | twist-2 | $P_1^{-1}P_2^{-1}$ |
| | | | $P_1^{-1}P_2^{-1}\cos\phi$ |
| | $\Re[\Delta C^{I}_{unp}(\mathcal{F})]$ | twist-2++ | $\frac{1}{P_1 P_2}$ |
| | $\Im[C^{I}_{unp}(\mathcal{F})]$ | twist-2 | $\frac{\lambda}{P_1 P_2}\sin\phi$ |
| | $\Re[C^{I}_{unp}(\mathcal{F}^{eff})]$ | twist-3 | $\frac{1}{P_1 P_2}\cos 2\phi$ |
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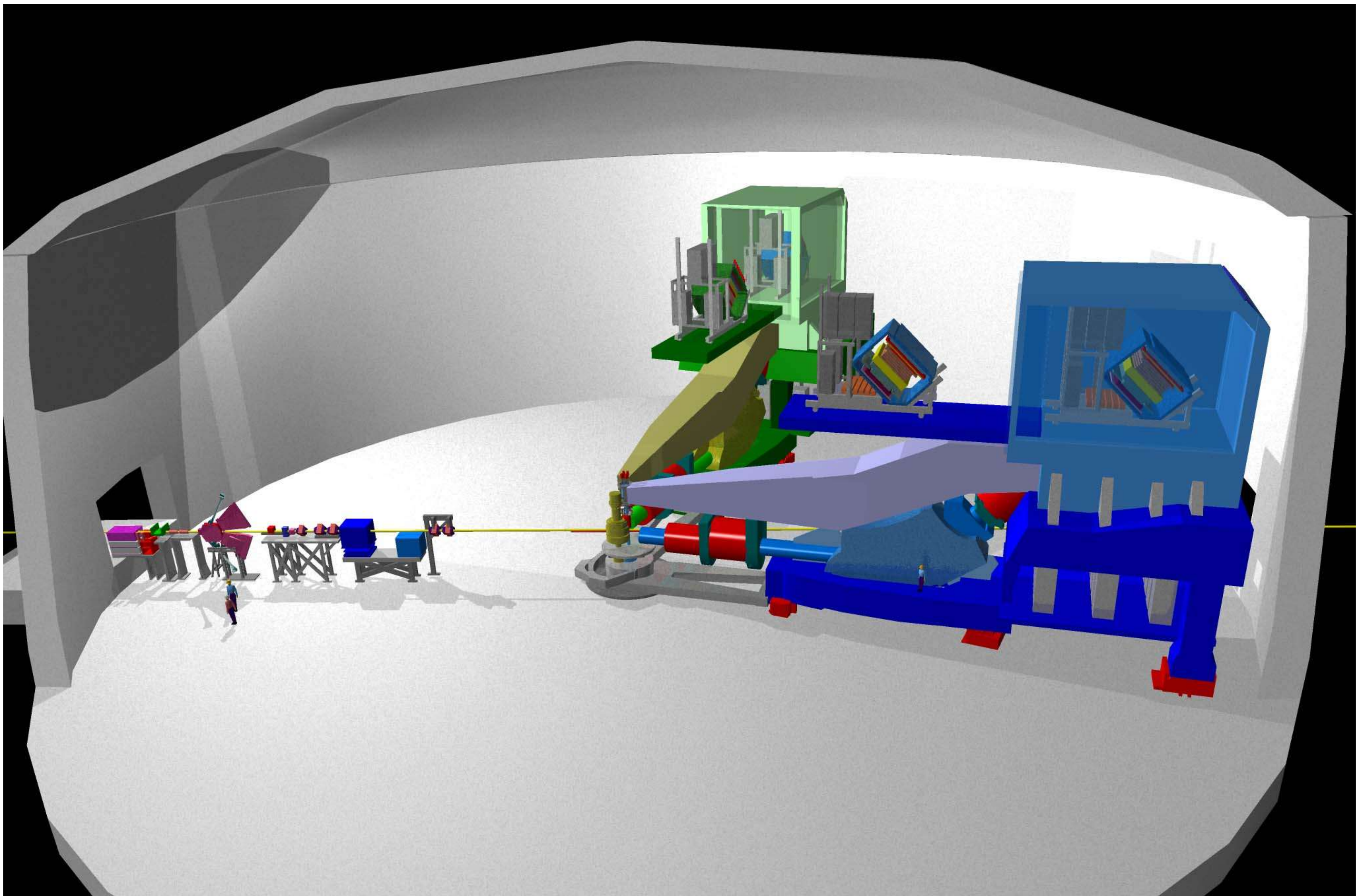
| | $\Re[C^{I}_{T,unp}(\mathcal{F}_T)]$ | twist-2 gluon | $\frac{1}{P_1 P_2}\cos 3\phi$ |

# 2- Apparatus for Hall A DVCS experiment

## Common Hall A apparatus

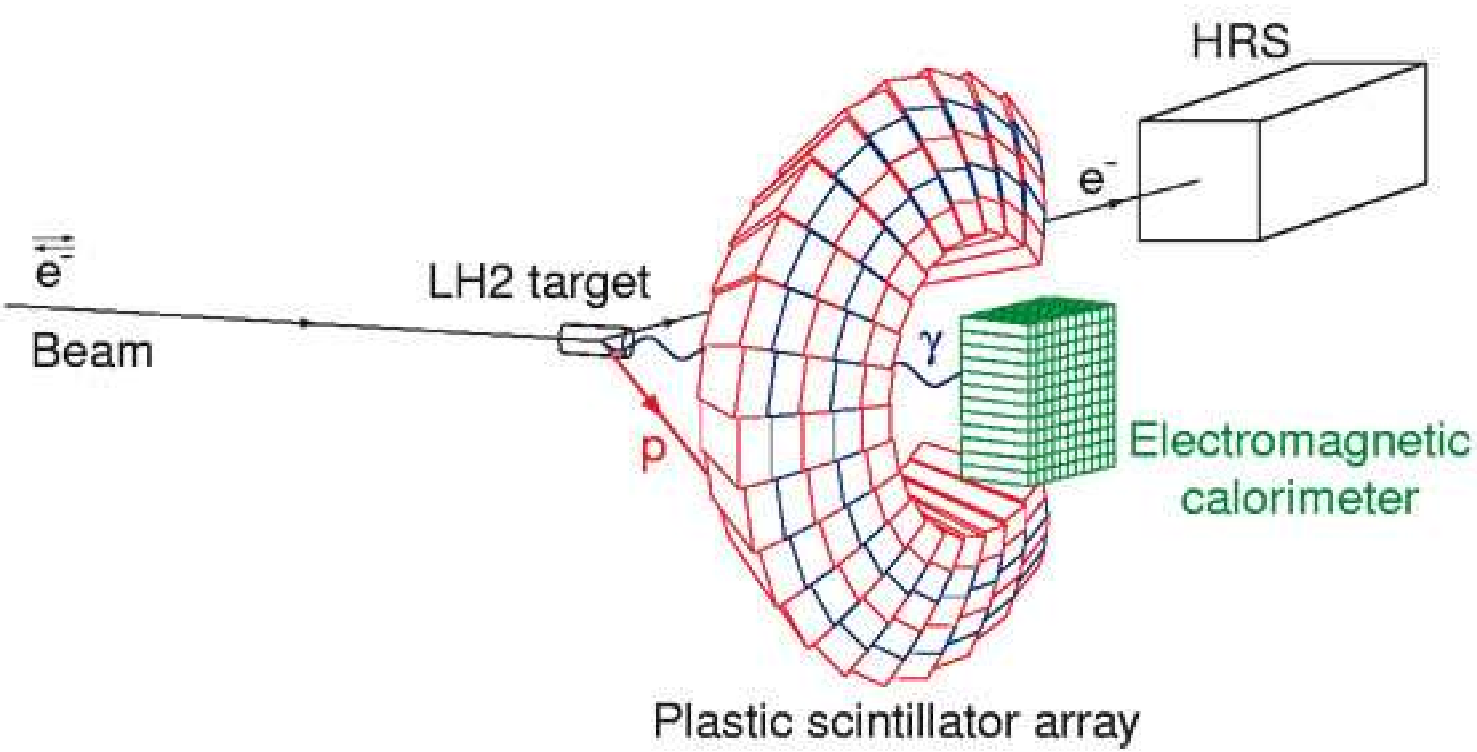


# 2- dedicated DVCS apparatus

DVCS in Hall A: E00-110 (p) and E03-106 (n):

– $PbF_2$ Electromagnetic calorimeter

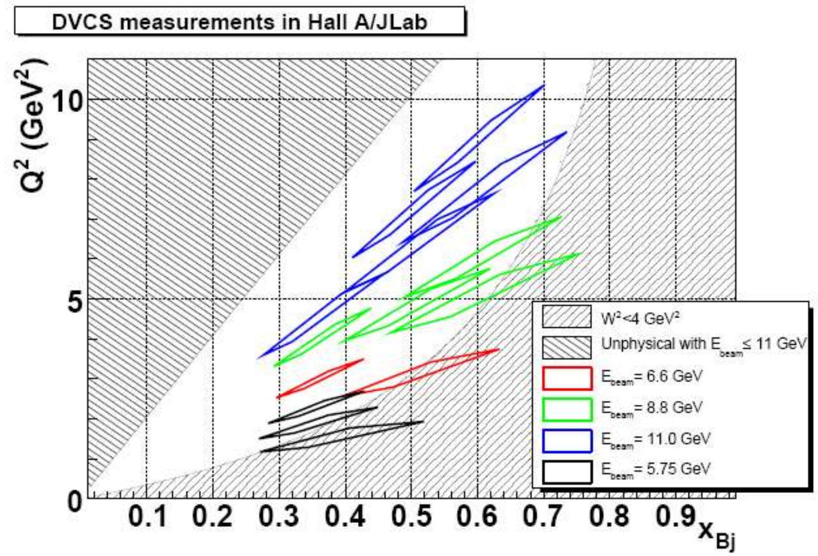
– Proton Array



# 3- Cross sections extraction method

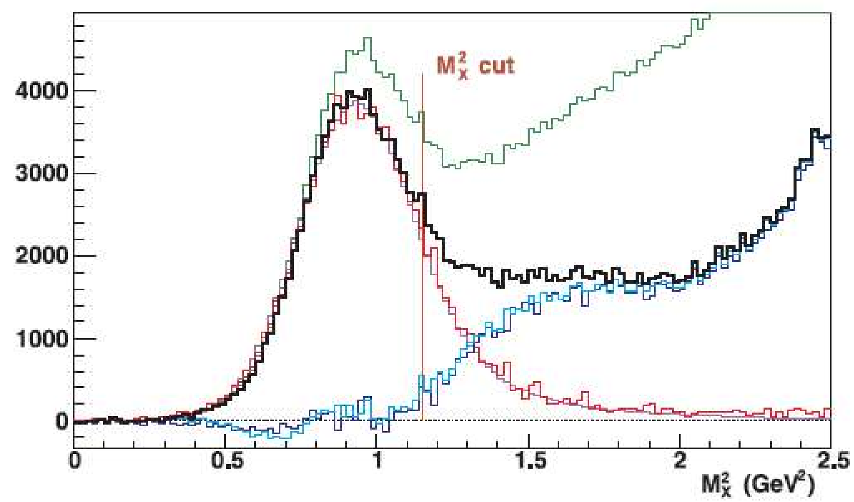
- Kinematical domain:

  3 kinematics




- Event selection:

  Cut on reconstructed missing mass



# 3- Cross sections extraction method

- Idea: Simulating DVCS events by MC

  -> at vertex, we have kinematic variables: $x_v = \left\{ k', x_{Bj}, Q^2, t, \varphi_e, \varphi_{\gamma\gamma} \right\}_v$

  -> The detectors measures another set of kinematic variables: $x_e = \left\{ k', x_{Bj}, Q^2, t, \varphi_e, \varphi_{\gamma\gamma} \right\}_e$

  => In the simulation, we compute mapping functions from vertex kinematic variables to measured ones : $K\left(x_e | x_v\right)$

- 11 independent quantities (observables): $X_j^{(\Lambda)}$

  with associated kinematic factors : $F^{(\Lambda)}(x_v)$

  => we can define mapping matrices as :

$$K_{i_e, j_v}^{(\Lambda)} = \int_{x_e \in Bin(i_e)} \int_{x_v \in Bin(j_v)} dR K\left(x_e | x_v\right) F^{(\Lambda)}(x_v)$$

# 3- Cross sections extraction method

=> That leads to an expected number of counts per bin:

$$Y^{MC}(i_e) = \left[\int Ldt\right] \sum_{j_v,\Lambda} K^{(\Lambda)}_{i_e,j_v} X^{(\Lambda)}_j$$

Fit with experimental data by a $\chi^2$ method to get our observables =>

$$\chi^2 = \sum_{i_e} \frac{\left[Y^{Exp}(i_e) - Y^{MC}(i_e)\right]^2}{\left[\sigma^{Exp}(i_e)\right]^2}$$

(Bethe Heitler, $\pi^0$ and accidental subtracted from experimental yields)

Finally, we get :

$$\Rightarrow \overline{X}^{(\Lambda)}_j = \sum_{j_v',\Lambda'} \left[\alpha^{-1}\right]^{(\Lambda),(\Lambda')}_{J_v,j_v'} \beta^{(\Lambda')}_{j_v}$$

with:

$$\alpha^{(\Lambda)(\Lambda')}_{i_e,j_v'} = \sum_{i_e} \left[\int Ldt\right]^2 K^{(\Lambda)}_{i_e,j_v} K^{(\Lambda')}_{i_e,j_v'} / \left[\sigma^{Exp}(i_e)\right]^2$$

$$\beta^{(\Lambda)(\Lambda')}_{i_e,j_v'} = \sum_{i_e} Y^{Exp}(i_e) \left[\int Ldt\right] K^{(\Lambda)}_{i_e,j_v} / \left[\sigma^{Exp}(i_e)\right]^2$$

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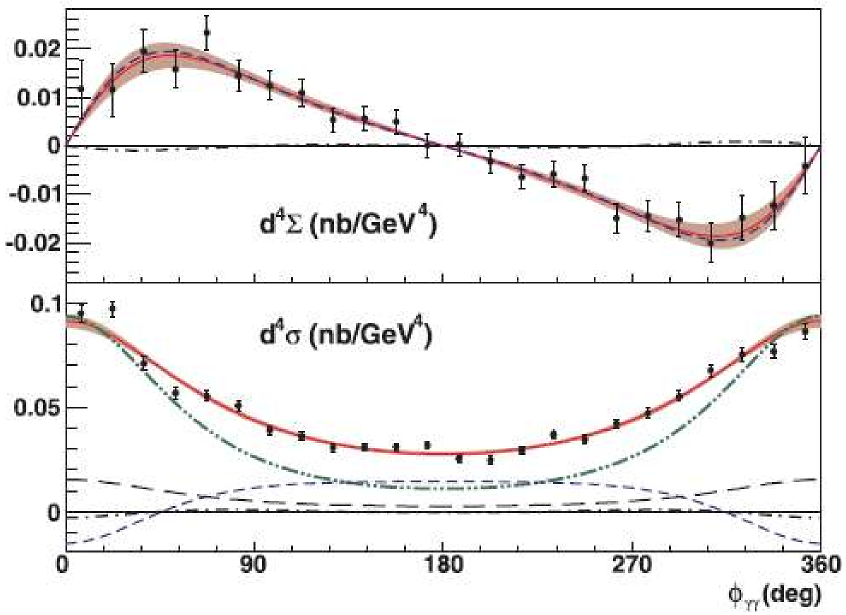
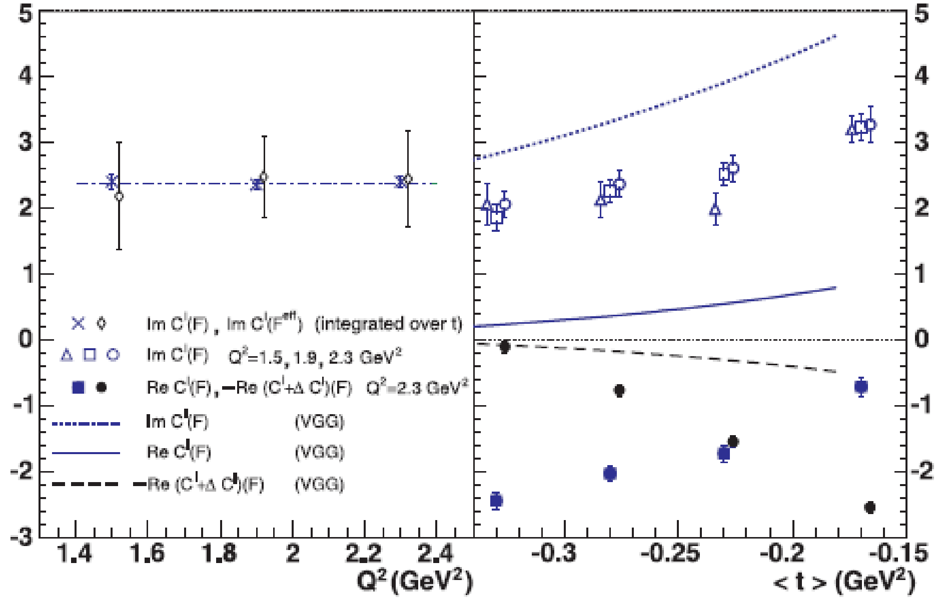
# 4- Results

*Carlos Muñoz-Camacho et al :* ***nucl-ex/0607029v2***

$x_{Bj}$ = 0.36, $Q^2$ = 2.3 GeV², t = 0.28 GeV²



# 4- Results

Remaining problems to resolve :

- 3 kinematics to have several constraints on the fit, and further on GPD's.

  Unfortunately, removing of neutral pions could have been performed **ONLY** at $Q^2$ = 2.3 GeV$^2$

  $\Rightarrow$Real part of interference terms cannot be extracted for $Q^2$ = 1.5 and 1.9 GeV$^2$:

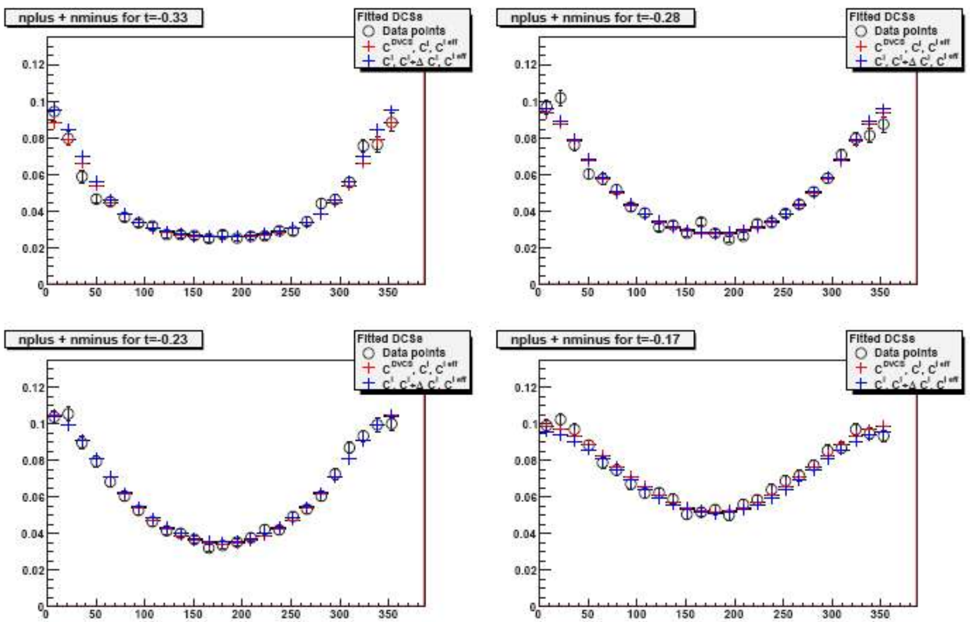
  -> May cause problems to extract GPD's
- Not able to fit real part of DVCS **AND** interference terms.

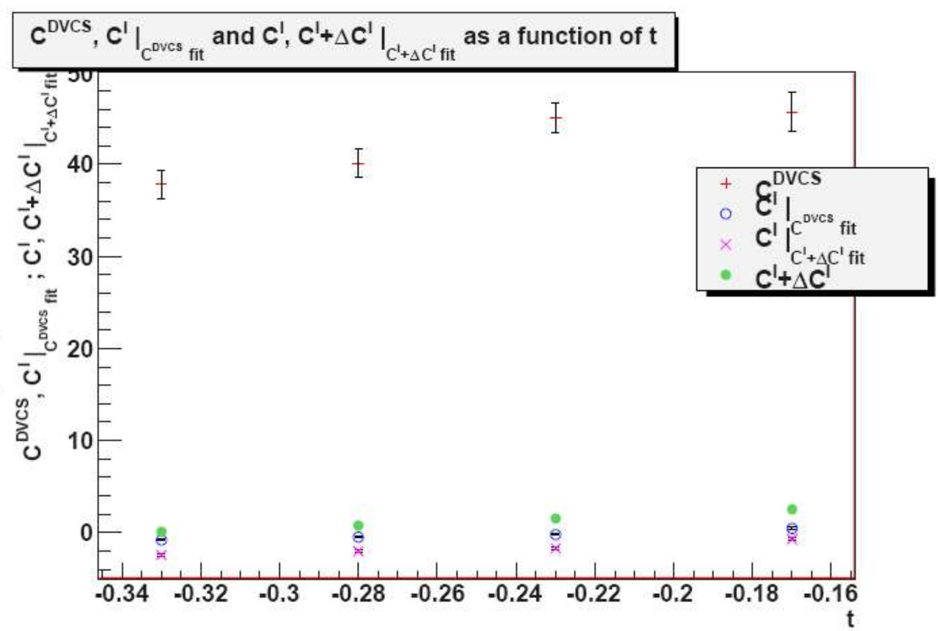
# 4- Results

Blue crosses: $C^{DVCS}(F,F^{*}) = 0$

Red crosses: $\Delta C^{I}(F) = 0$

Black open circles: Data



# 5- Conclusions

- First DVCS experiment in Hall A was a success:

  - scaling, at least for imaginary part of $C^I(F)$

  - First unpolarized DVCS cross sections in valence quark region ($x_{Bj}$>0.1)

- BUT, there are still problems to fix.

  => necessity of getting new events with improved apparatus

  => Next Hall A DVCS experiment (May 2009)